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RESEARCH MEMORANDUM

EFFECT OF SPIKE-TIP AND COWL-LIP BLUNTING ON INLET PERFORMANCE OF A MACH 3.0 EXTERNAL-COMPRESSION INLET

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Cleveland, Ohio

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT OF SPIKE-TIP AND COWL-LIP BLUNTING ON INLET PERFORMANCE OF A MACH 3.0 EXTERNAL-COMPRESSION INLET*

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SUMMARY

The effect of inlet component blunting on performance was investigated with an axisymmetric external-compression inlet in the Lewis 10- by 10-foot supersonic wind tunnel at a Mach number of 3.0 and a Reynolds number of 2.5×10^6 per foot. The investigation was conducted to determine the performance penalties associated with spike-tip and cowl-lip blunting. The reported data should be useful as a design guide for blunt inlet components applicable to cooling techniques.

The data indicated no marked change in inlet performance with slight blunting of both spike ($r_{tip}/r_{inlet} = 0.017$) and cowl lip ($r_{lip}/r_{inlet} = 0.0042$), while a combination of the bluntest spike and cowl lip ($r_{tip}/r_{inlet} = 0.068$ and $r_{lip}/r_{inlet} = 0.0170$, respectively) reduced the over-all peak pressure recovery about 6 counts. For this investigation the cowl-lip angles were simultaneously reduced as the blunting was increased, resulting in essentially constant cowl pressure drag for all degrees of cowl-lip blunting. The cowl pressure-drag rise was only 0.007 for the range of lip bluntness studied.

INTRODUCTION

Analysis indicates that air-breathing engines are a feasible means of propulsion at high Mach numbers. At these flight speeds aerodynamic heating can raise the surface temperatures above the allowable limits, especially near stagnation regions such as the cowl lip and spike tip. One method of reducing the high stagnation-point heat flux to these regions is to use bluntness. In doing so, space is also provided to house a cooling system in the event one is needed. Although no major aerodynamic heating problem is apparent at a Mach number of 3.0, the data reported herein and information presented in reference 1 at a Mach number

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of 4.95 should be useful in making an intelligent compromise between structural and aerodynamic requirements for a high Mach number design inlet. The investigation was conducted at a Mach number of 3.0 and at a Reynolds number of 2.5×10^6 per foot in the NACA Lewis 10- by 10-foot supersonic wind tunnel.

SYMBOLS

A_{in}	inlet capture area, 1.183 sq ft
A_{max}	maximum projected frontal area of model, 1.483 sq ft
A_3	diffuser-exit flow area, 0.961 sq ft
C_D	drag coefficient, $D/q_0 A_{max}$
C_p	pressure coefficient, $(p_l - p_0)/q_0$
D	drag
m_3/m_0	inlet mass-flow ratio, $\rho_3 V_3 A_3/\rho_0 V_0 A_{in}$
P	total pressure
$\bar{P}_3/P_0$	total-pressure recovery
$\frac{P_{3,max} - P_{3,min}}{\bar{P}_3}$	distortion parameter
p	static pressure
q	dynamic pressure
r	radius
V	velocity
α	angle of attack
θ	spike-position parameter, angle between axis of symmetry and line from spike tip (projected tip on blunt spikes) to point of focused compression
ρ	density of air

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Subscripts:

c	cowl
e	external
in	inlet
int	internal
l	local
lip	lip
max	maximum
min	minimum
t	tip
0	conditions in free stream
3	conditions at diffuser exit

Superscript:

$\bar{}$	area-weighted value

APPARATUS AND PROCEDURE

The basic test vehicle, a 16.46-inch-maximum-diameter, 102-inch-long model, is shown installed in the test section in figure 1. The model employed an axisymmetric external-compression inlet with interchangeable cowls and spike tips. A scale drawing of the inlet with maximum component bluntness, including the spike coordinates, is presented in figure 2.

Scale drawings of the interchangeable spike tips and cowls along with the cowl coordinates are given in figure 3. The basic isentropic compression spike was designed by the method of reference 2 with the point of focused compression at the cowl lip. The spike had an initial cone half-angle of 13.65°, with a maximum of 35° of compressive turning, and a design spike-position parameter θ of 23.60°. The interchangeable spike tips were of 0-, 1/8-, 1/4-, and 1/2-inch radii, having respective radius ratios r_t/r_{in} of 0, 0.017, 0.034, and 0.068 (r_{in} = 7.365 in.).

The streamline at the focal point of the compression field generated by the sharp-tipped spike determined the contour of the internal surface of the sharp-lip cowl; the surface was designed to capture the flow without inducing any internal compression. Cowl-lip bluntness was achieved by adding various lip radii to the point of focused compression symmetrically with respect to the focal-point streamline. This design method resulted in lower external lip angles for the more rounded leading-edge cowls. Cowl-lip radii of 0, 1/32, 1/16, and 1/8 inch, corresponding to radius ratios r_{lip}/r_{in} of 0, 0.0042, 0.0085, and 0.0170, with respective external lip angles of 42°, 40°, 38°, and 33° were investigated. All of the cowls under consideration had a projected area 20 percent of the maximum frontal area.

The cowls were extensively surveyed with static-pressure orifices, which when integrated over the projected cowl area determined the cowl pressure drag. The cowl pressure drag is defined as the force acting on that portion of the cowl between the stagnation point and the beginning of the external cylindrical section of the model. All the configurations were tested with a ram-scoop boundary-layer-bleed system at the spike shoulder, removing approximately 5 percent of the maximum capture mass flow (fig. 2). A force balance was employed in the model, from which the total external drag was obtained.

RESULTS AND DISCUSSION

All of the performance data presented were obtained at a free-stream Mach number of 3.0. Performance of the sharp-lip cowl with the various spike tips is presented in figure 4. Because of the nonfocusing of the compression shock system, improvement in mass-flow characteristics could be obtained by retracting the spike a small amount from the design point; however, slight losses in peak pressure recovery resulted in most instances. In one case (fig. 4(c)), the loss in peak recovery reached approximately 5 counts. Considering the design spike position (θ = 23.60°), spike-tip blunting had no marked effect on the inlet mass-flow characteristics. The small differences noted can be attributed to the tolerances in the spike-translation unit. This indicates that, within the blunting tested, the shock structure is essentially independent of the tip contour and is a function only of the basic spike design.

The effect of rounding the spike tip on inlet performance with blunt-leading-edge cowls is presented in figures 5 to 7. The results indicate a trend similar to that of the data for blunted spike tips with sharp cowl. Blunting the spike from a sharp tip to a radius ratio of 0.068 in combination with the cowls of various radius ratios reduced the peak pressure recoveries approximately 3 counts, as can be seen in figures 5, 6, and 7. Comparison of figures 4(a) and (d) with figures 5

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to 7 shows a decrease of 1 to 4 counts in mass flow when the cowl lip is blunted. This occurs because the stagnation point moves inside the cowl lip as blunting is added to the cowl lip.

The over-all drag coefficients as affected by spike blunting are shown in figure 4. Only the bluntest spike (radius ratio = 0.068) caused an increase in the over-all drag coefficient, on the order of 0.02, probably as a result of a small amount of spillage. The slope of the drag curves during subcritical inlet operation appeared to be constant for the various degrees of spike blunting investigated. However, when blunting was added to the cowl lip, the total drag coefficient progressively increased, probably because of additive drag due to the attendant spillage.

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The flow distortion was essentially unaffected by blunting of the inlet components, maximum distortion values of only 0.04 being recorded.

The effect of spike-tip blunting on performance is summarized in figure 8. In all cases the peak and critical pressure recoveries were only slightly influenced by spike blunting. In general, pressure recoveries were reduced approximately 2 counts as a result of rounding the tip from a pointed spike to a radius ratio of 0.068 spherical nose.

Figure 9 summarizes the effects of cowl-lip blunting on inlet performance. The curves in the figure without established data points were obtained from figure 8. Rounding the cowl leading edge to a radius ratio of 0.0085 had only small adverse effects on the inlet performance. Increasing the cowl-lip radius ratio to the maximum of 0.0170 decreased critical pressure recovery approximately 8 counts (fig. 9(a)). It is apparent from summary figures 8 and 9 that a small degree of inlet component blunting, with a radius ratio of 0.017 for the spike and a radius ratio of 0.0042 for the cowl lip, resulted in essentially no adverse effects on the inlet performance.

The design method employed in the cowl-lip design resulted in lower external lip angles for the blunter cowls. The effect of external lip angle and cowl-lip blunting on the cowl pressure drag during critical inlet operation is presented in figure 10. Experimental drag data of cowls with a sharp leading edge (ref. 3) having the same ratio of projected cowl area to the maximum frontal area (0.20) and with contours similar to those of the present tests are compared with the present data in figure 10(a). The drag penalty associated merely with the rounding of the cowl leading edge from a sharp lip to a radius ratio of 0.0170 is depicted by the shaded region in the figure. Comparing the drag coefficient of the cowls tested, it is apparent that the reduction in external lip angle was approximately enough to counterbalance the drag rise resulting from blunting, leaving only a rise of 0.007 going from sharp to the

most blunt. However, the drag rise due to blunting can be considerable, as indicated by comparing the sharp-cowl value with the blunt. As seen in figure 10(a), this rise can be as much as 0.074 for a cowl with external lip angle of 33° and a radius ratio of 0.0170. For the data of this report, the drag penalty due to blunting appears to be linear with increasing lip bluntness, as shown in figure 10(b).

Typical pressure distributions over the cowl surfaces are shown in figure 11. The extensive static-pressure instrumentation revealed that the stagnation streamline moved inward with increasing cowl bluntness.

Schlieren photographs of supercritical inlet operation with the various spike tips and the sharp cowl are shown in figure 12. A linear projection forward of the established conical shock wave on the blunt spike intersects at a point ahead of the sharp spike tip, but the established shock wave angle is less than that of the one generated by the sharp-tip cone. These compensating effects appeared to make the location of the initial spike shock wave with respect to the cowl lip essentially independent of the spike-tip bluntness.

CONCLUDING REMARKS

The effect of cowl-lip and spike-tip blunting on inlet performance was investigated on an axisymmetric external-compression inlet at a Mach number of 3.0. Slight blunting of the inlet components (radius ratio of 0.017 for the spike tip and radius ratio of 0.0042 for the cowl leading edge) had no apparent adverse effects on inlet performance. The combination of the most blunt spike (radius ratio of 0.068) and cowl (radius ratio of 0.0170) reduced the peak pressure recovery about 6 counts. Although there would be an appreciable drag penalty associated with blunting the cowl leading edge while maintaining the external lip angle constant, the blunting can be done so that the external lip angle is reduced, thus reducing the drag penalty associated with blunting.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 16, 1958

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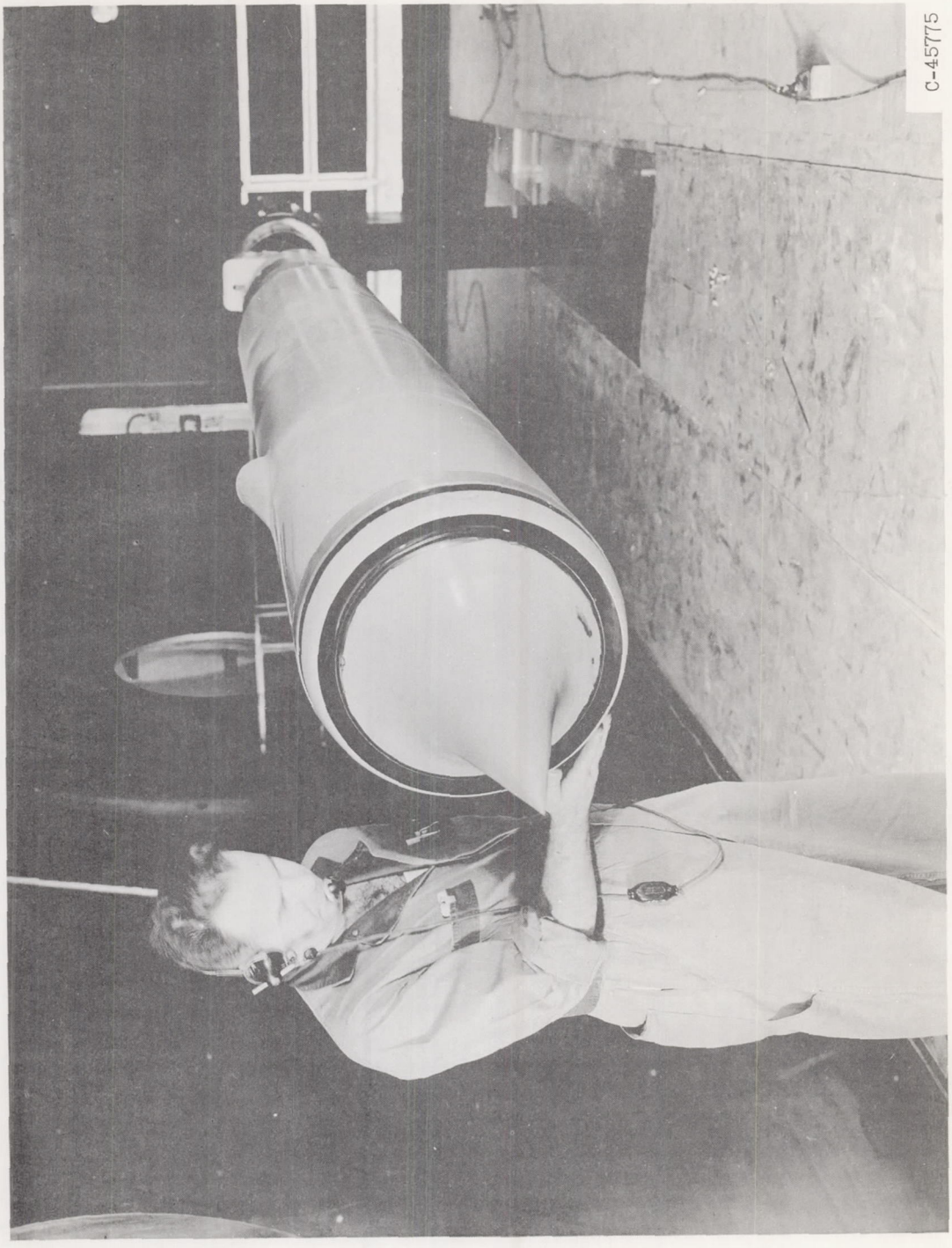


Figure 1. - Model installed in test section.

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Basic spike coordinates	
x, in.	y_{rad}, in.
0	0 } Straight
7.081	1.726 } taper
8.276	2.019
9.143	2.238
10.652	2.687
11.868	3.102
12.870	3.489
13.696	3.847
14.375	4.174
14.946	4.485
15.419	4.773
15.822	5.039

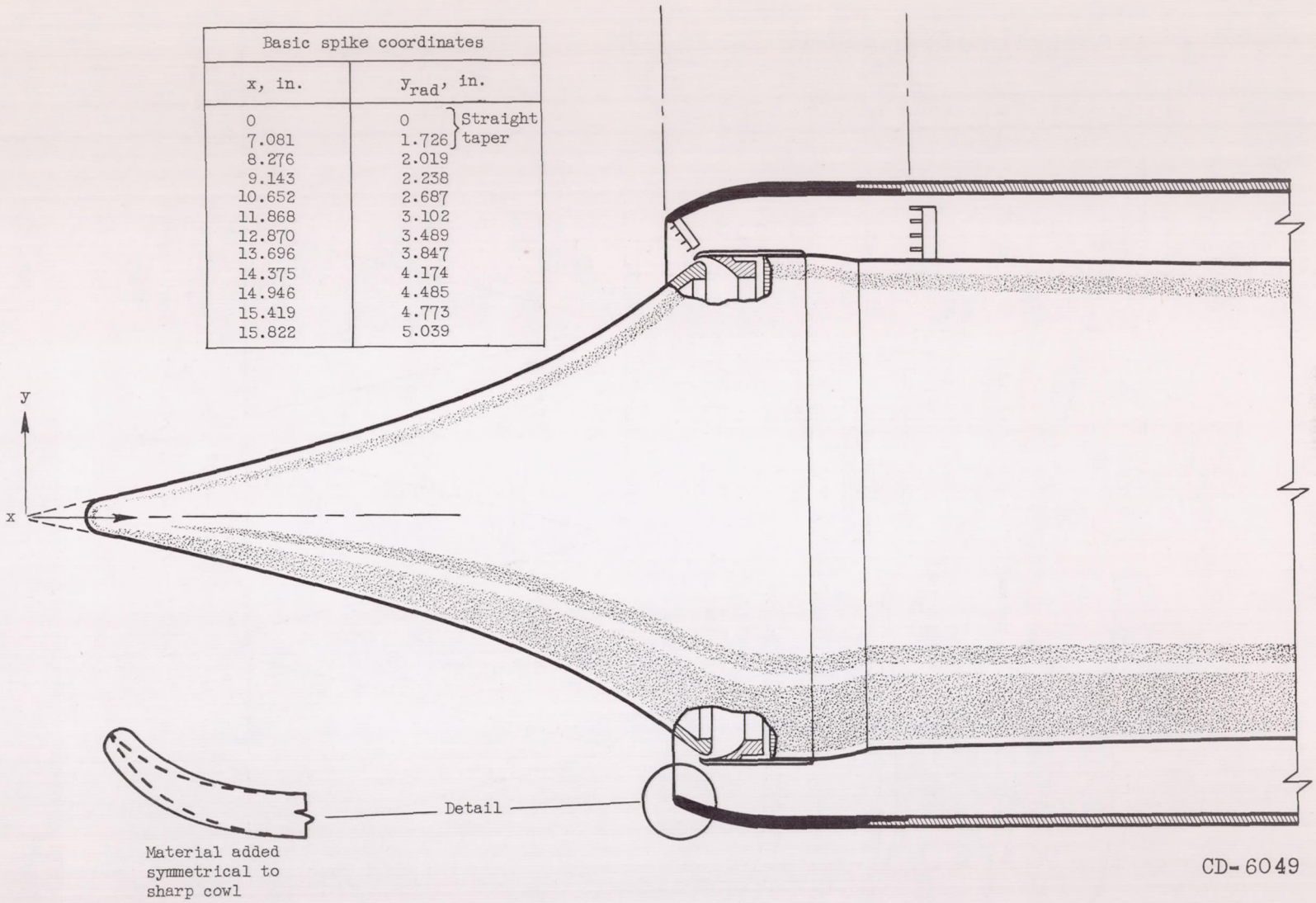
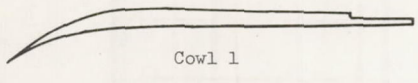
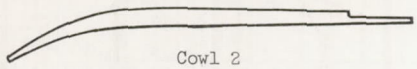


Figure 2. - Scale drawing of basic inlet with maximum bluntness.



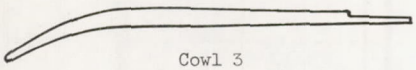
Cowl 1

r_{lip}/r_{in} = 0; External lip angle = 42°



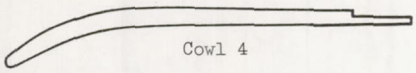
Cowl 2

r_{lip}/r_{in} = 0.0042; External lip angle = 40°



Cowl 3

r_{lip}/r_{in} = 0.0085; External lip angle = 38°

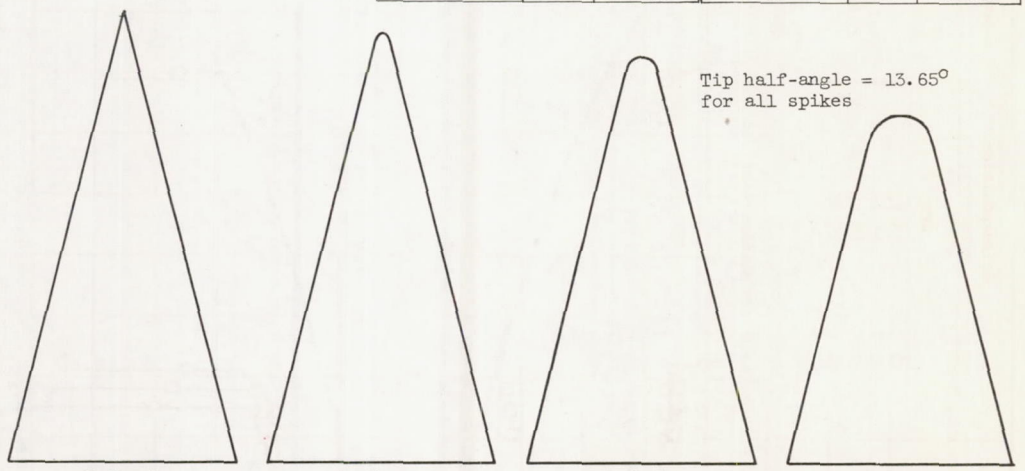


Cowl 4

r_{lip}/r_{in} = 0.0170; External lip angle = 33°

Cowl coordinates

Cowl 1			Cowl 2		
Distance from stagnation point, in.	r_e, in.	r_{int}, in.	Distance from stagnation point, in.	r_e, in.	r_{int}, in.
0	7.365	7.365	0	7.390	7.365
.2	7.540	7.480	.2	7.570	7.442
.4	7.682	7.575	.4	7.710	7.545
.6	7.810	7.659	.6	7.827	7.638
.8	7.913	7.728	.8	7.925	7.708
1.0	8.000	7.785	1.0	8.011	7.769
1.2	8.070	7.835	1.2	8.080	7.819
1.4	8.124	7.863	1.4	8.136	7.858
1.8	8.197	7.900	1.9	8.176	7.900
2.2	8.230	Straight taper	2.2	8.230	Straight taper
6.38	8.23	8.040	6.38	8.23	8.040
Cowl 3			**Cowl 4**		
0	7.430	7.365	0	7.490	7.365
.2	7.590	7.415	.2	7.640	7.341
.4	7.722	7.522	.4	7.760	7.460
.6	7.837	7.614	.6	7.862	7.562
.8	7.932	7.690	.8	7.953	7.650
1.0	8.013	7.755	1.0	8.028	7.722
1.2	8.078	7.806	1.2	8.089	7.783
1.4	8.132	7.845	1.4	8.138	7.835
1.90	8.208	7.900	2.10	8.220	7.918
2.20	8.230	Straight taper	2.20	8.230	Straight taper
6.38	8.230	8.040	6.38	8.23	8.040

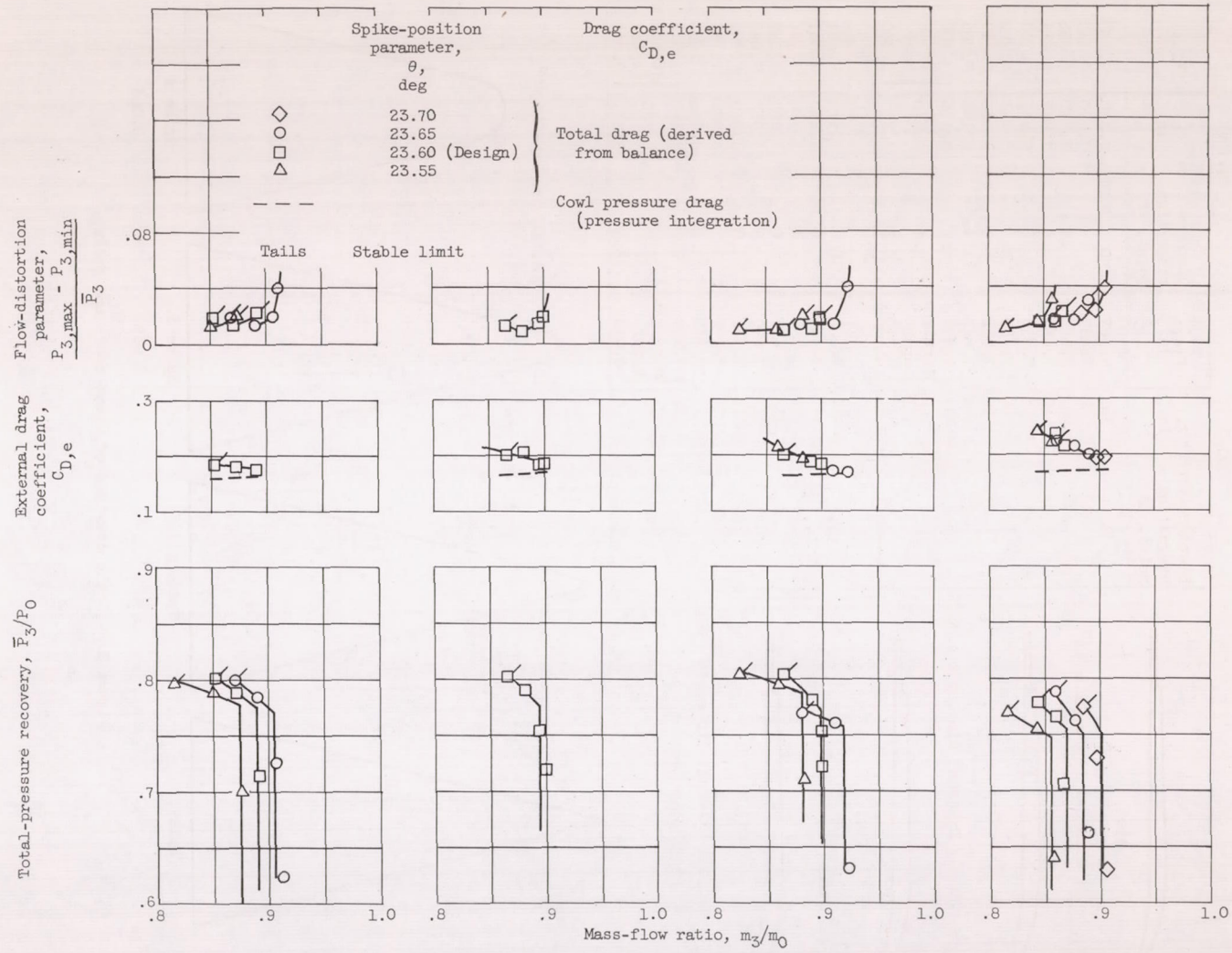


	Spike 1	Spike 2	Spike 3	Spike 4
r_t/r_{in}	0	0.017	0.034	0.068

Figure 3. - Scale drawings of blunt cowls and spikes.

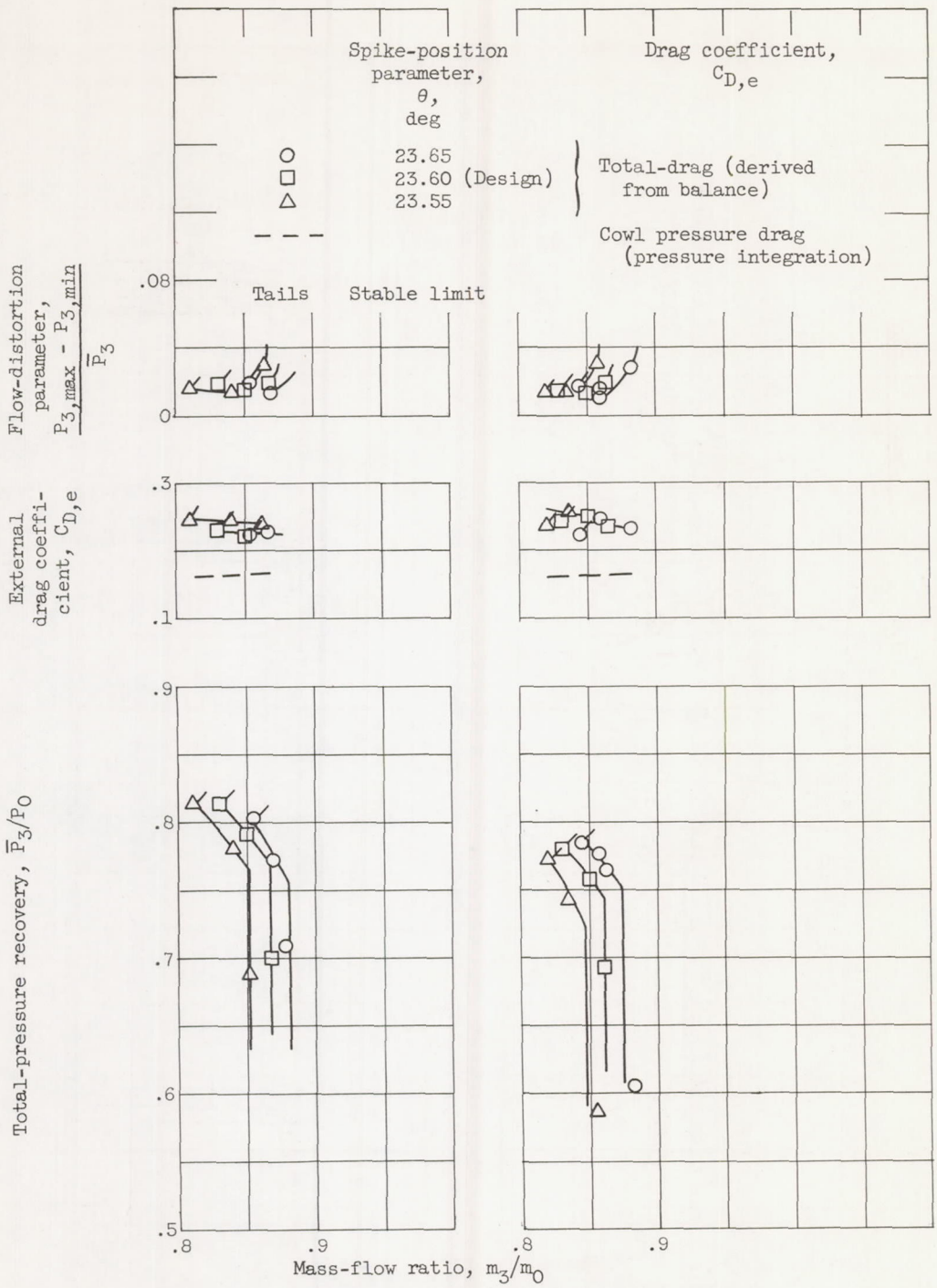
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(a) Spike 1: r_t/r_{in}, 0. (b) Spike 2: r_t/r_{in}, 0.017. (c) Spike 3: r_t/r_{in}, 0.034. (d) Spike 4: r_t/r_{in}, 0.068.

Figure 4. - Effect of spike-tip blunting at Mach number of 3.0 and cowl radius ratio of 0.



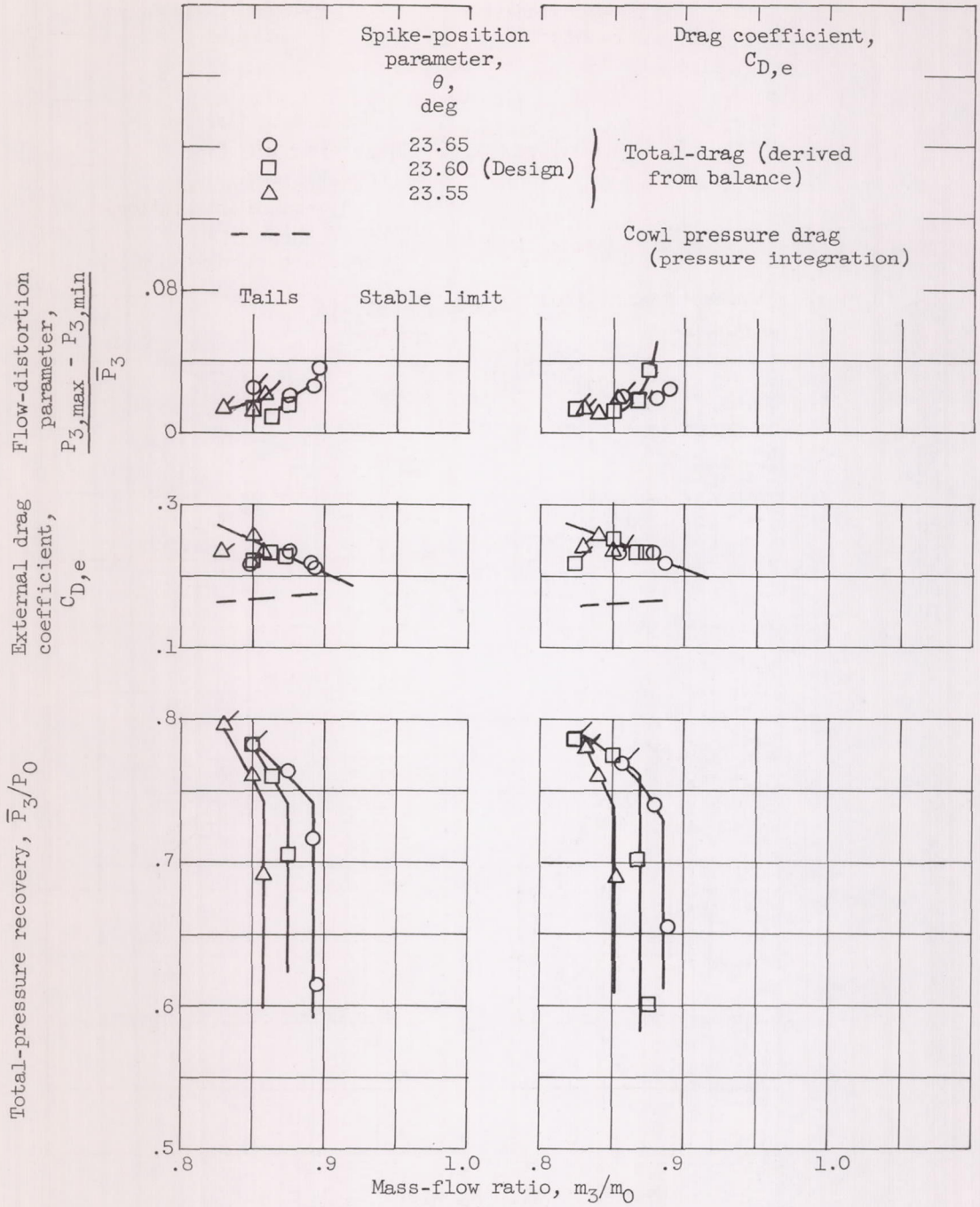
(a) Spike 1: r_t/r_{in}, 0.

(b) Spike 4: r_t/r_{in}, 0.068.

Figure 5. - Effect on inlet performance of cowl-lip blunting (r_{lip}/r_{in} = 0.0042) at Mach number 3.0 with and without spike-tip blunting.

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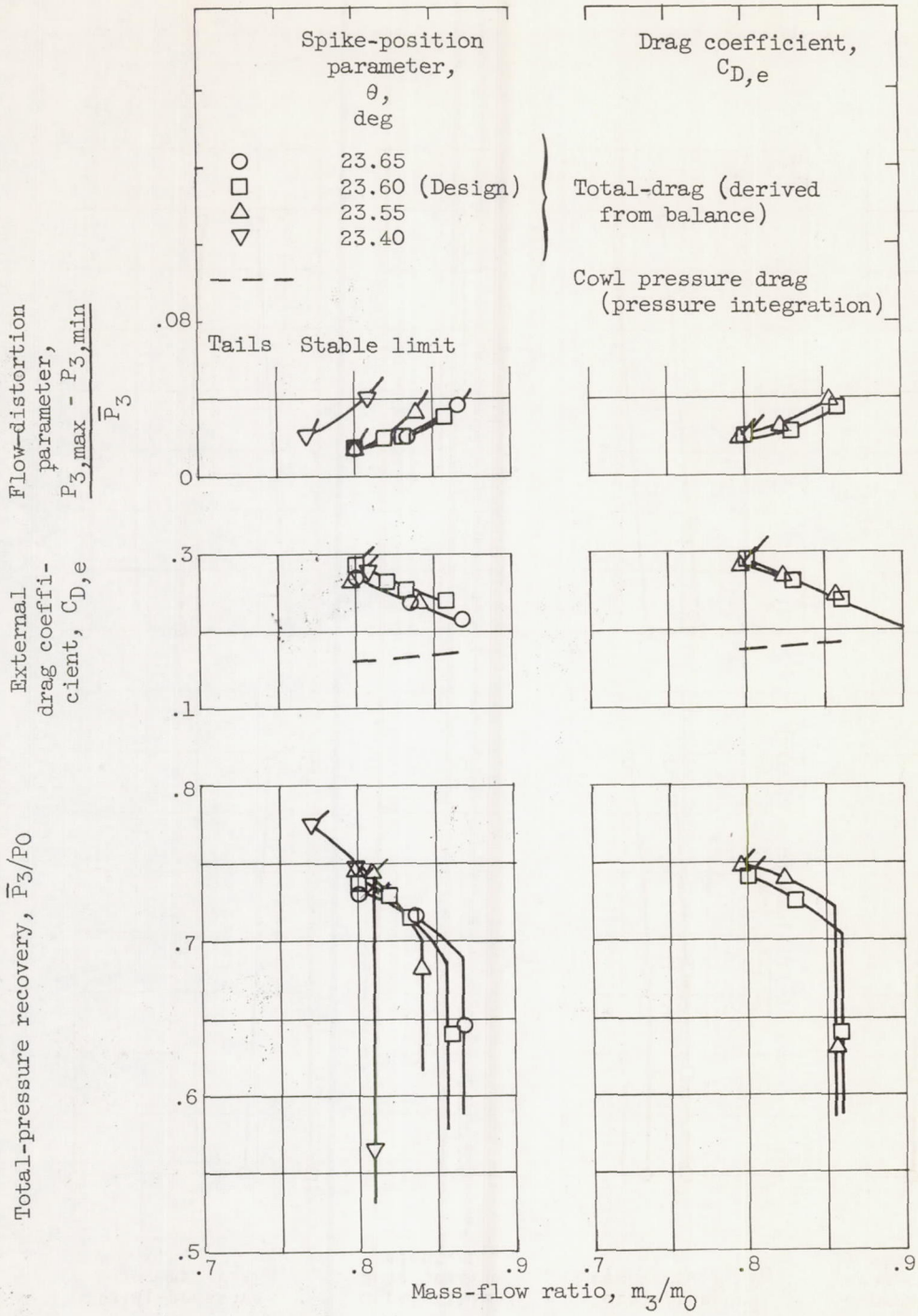


(a) Spike 1: r_t/r_{in}, 0. (b) Spike 4: r_t/r_{in}, 0.068.

Figure 6. - Effect on inlet performance of cowl-lip blunting (r_{lip}/r_{in} = 0.0085) at Mach number 3.0 with and without spike-tip blunting.

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(a) Spike 1: r_t/r_{in}, 0. (b) Spike 4: r_t/r_{in}, 0.068.

Figure 7. - Effect on inlet performance of cowl-lip blunting (r_{lip}/r_{in} = 0.0170) at Mach number 3.0 with and without spike-tip blunting.

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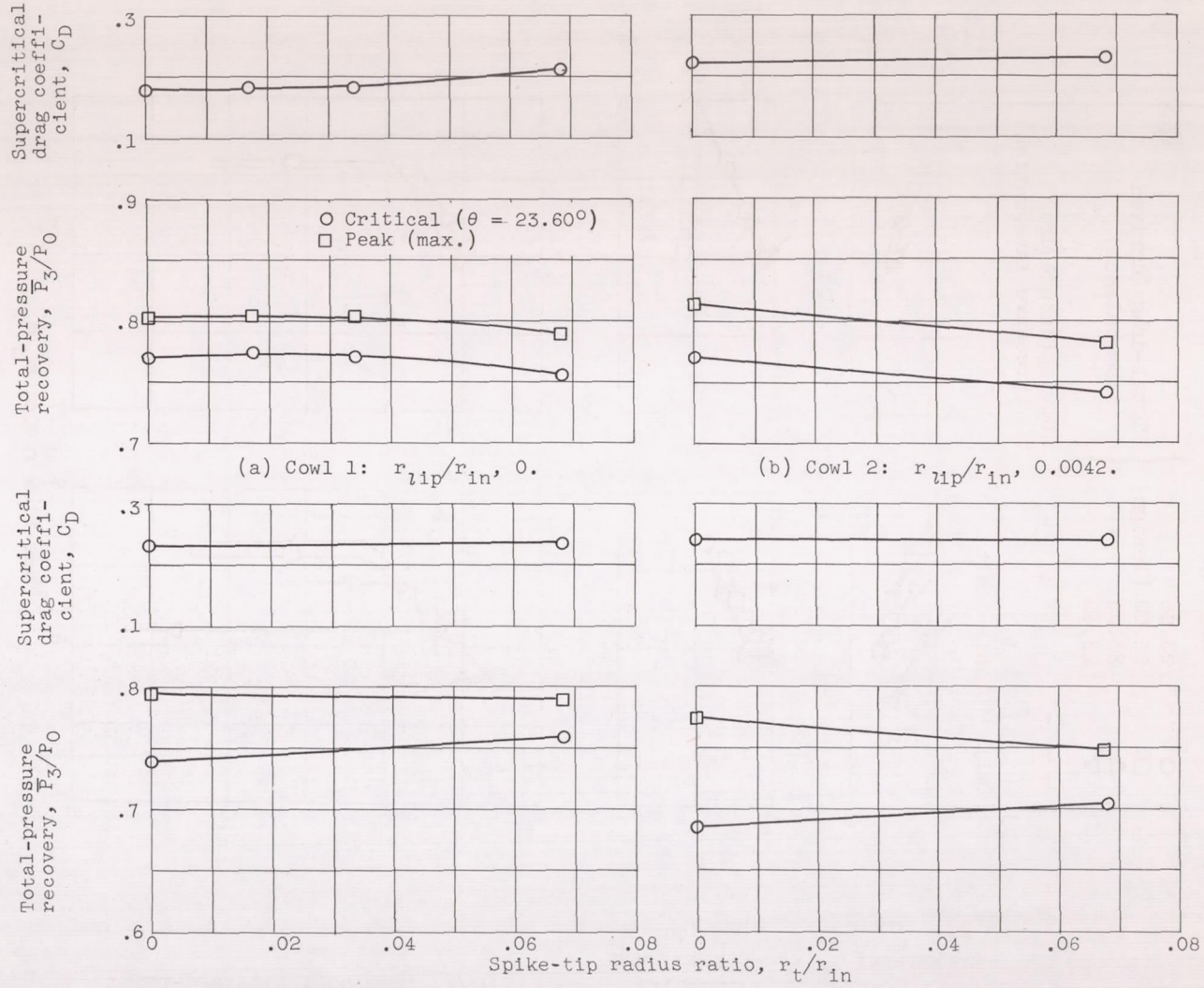


Figure 8. - Effect of spike-tip blunting on performance.

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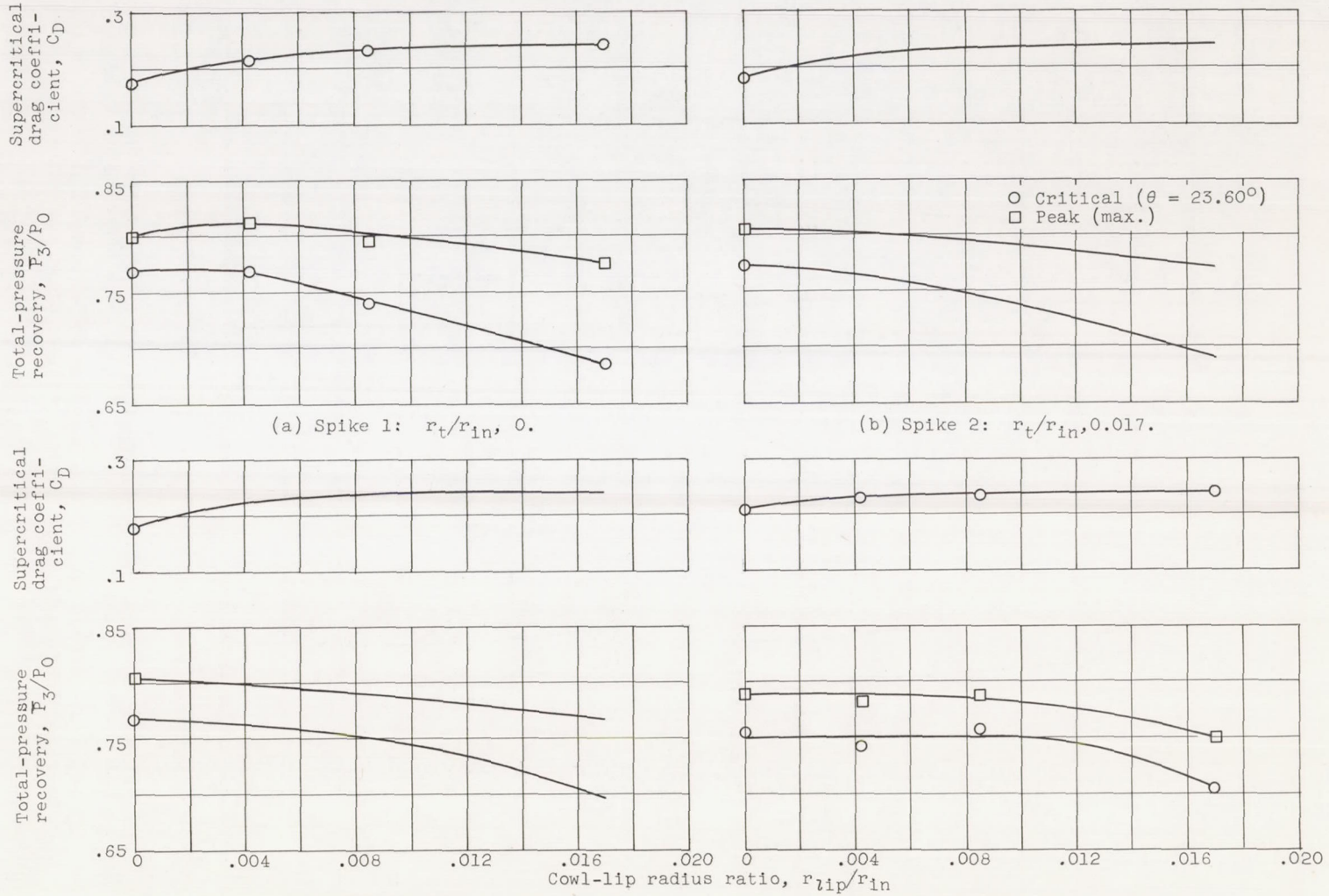
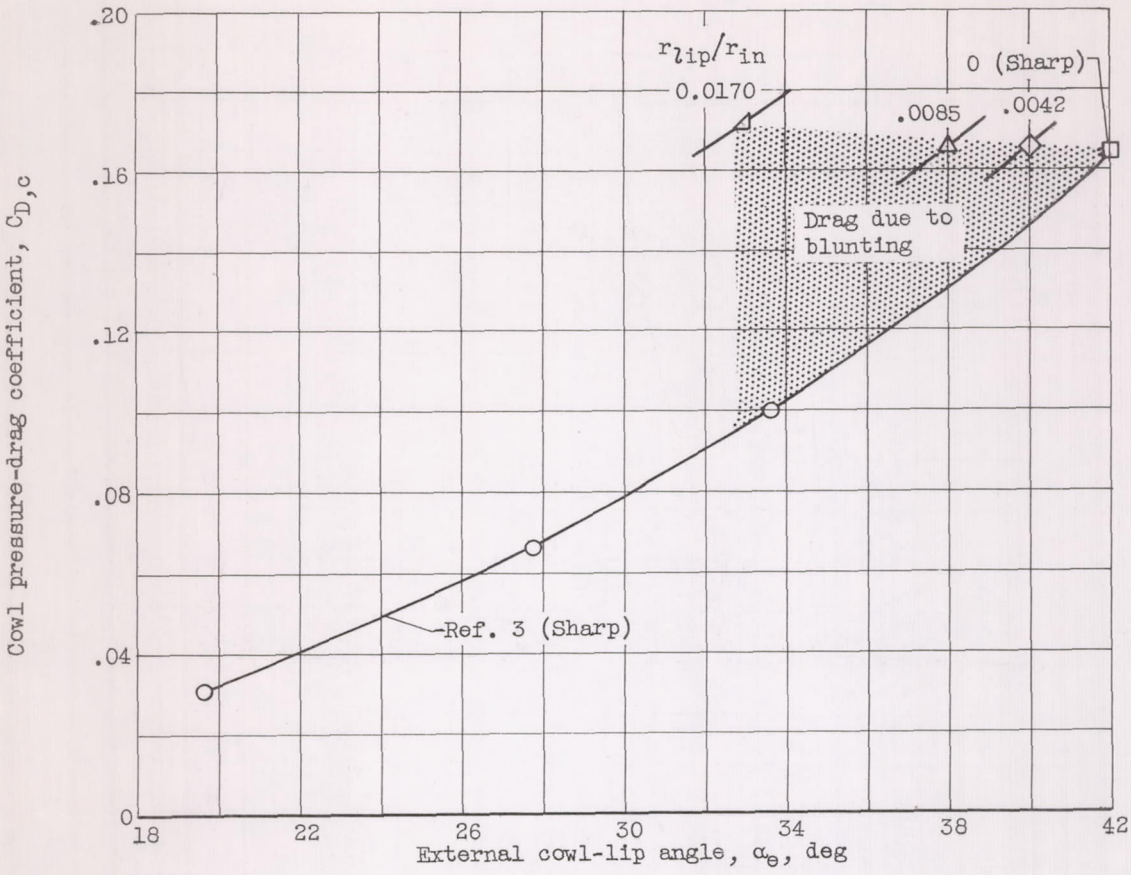


Figure 9. - Effect of cowl-lip blunting on performance.

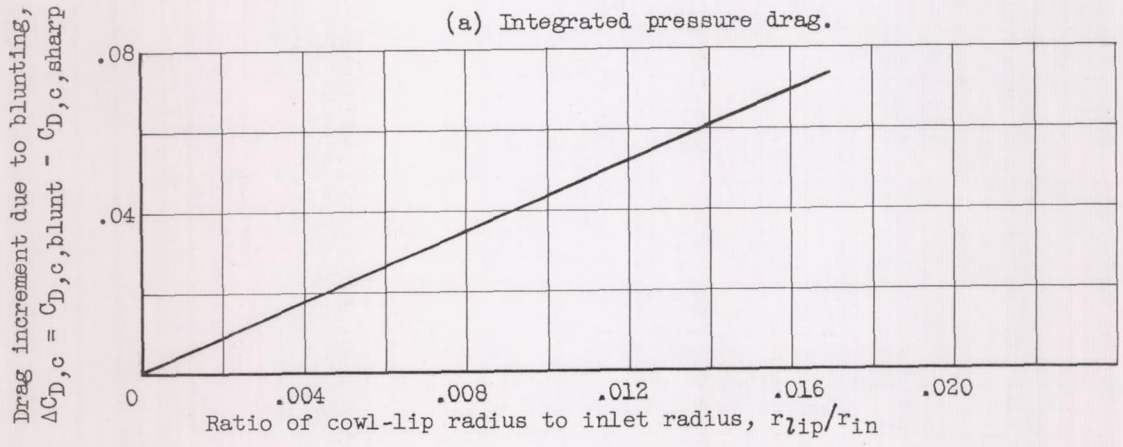
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(a) Integrated pressure drag.



(b) Drag increment due to blunting.

Figure 10. - Effect of cowl-lip blunting and external lip angle on cowl pressure-drag coefficient during critical inlet operation.

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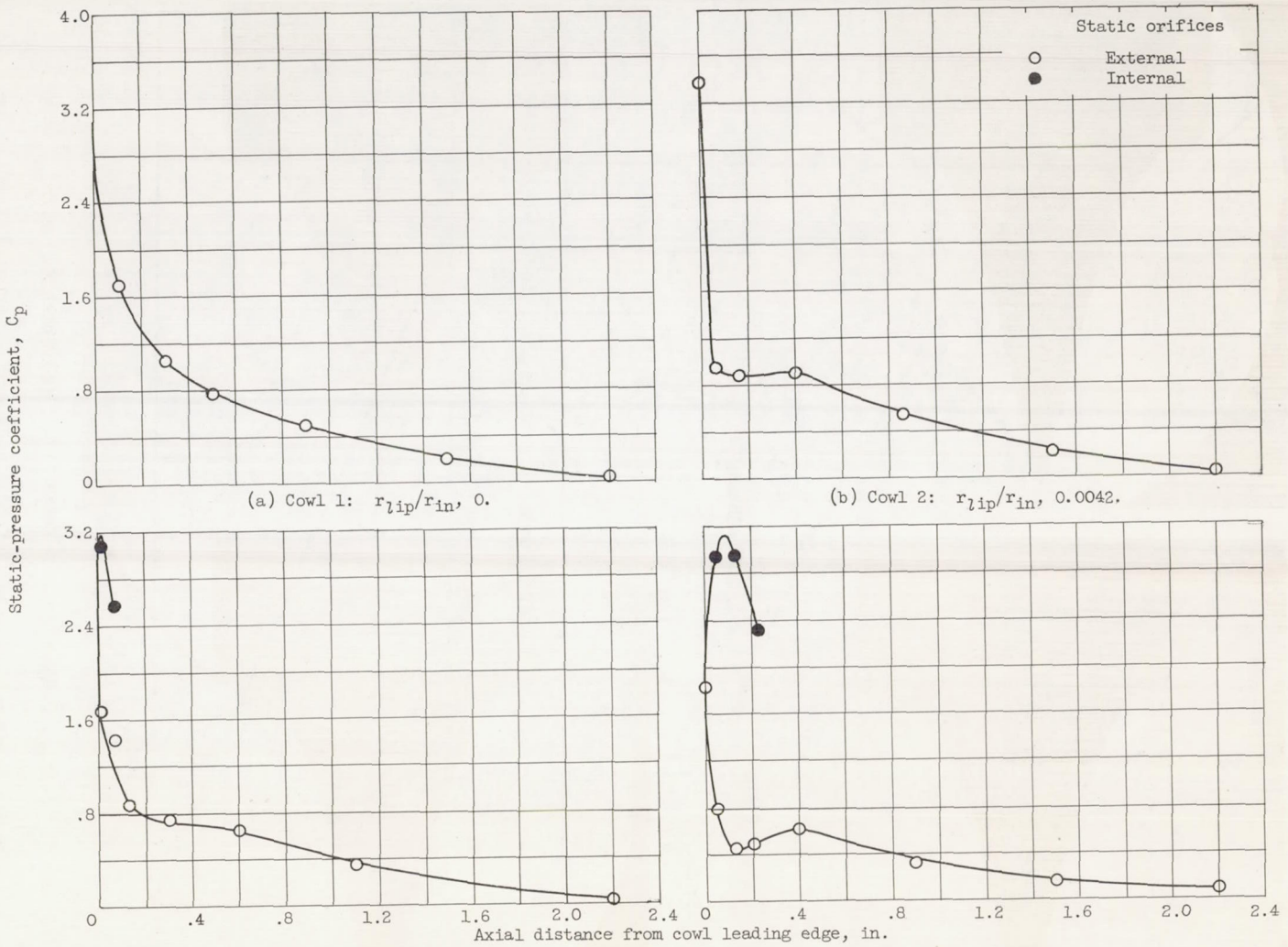
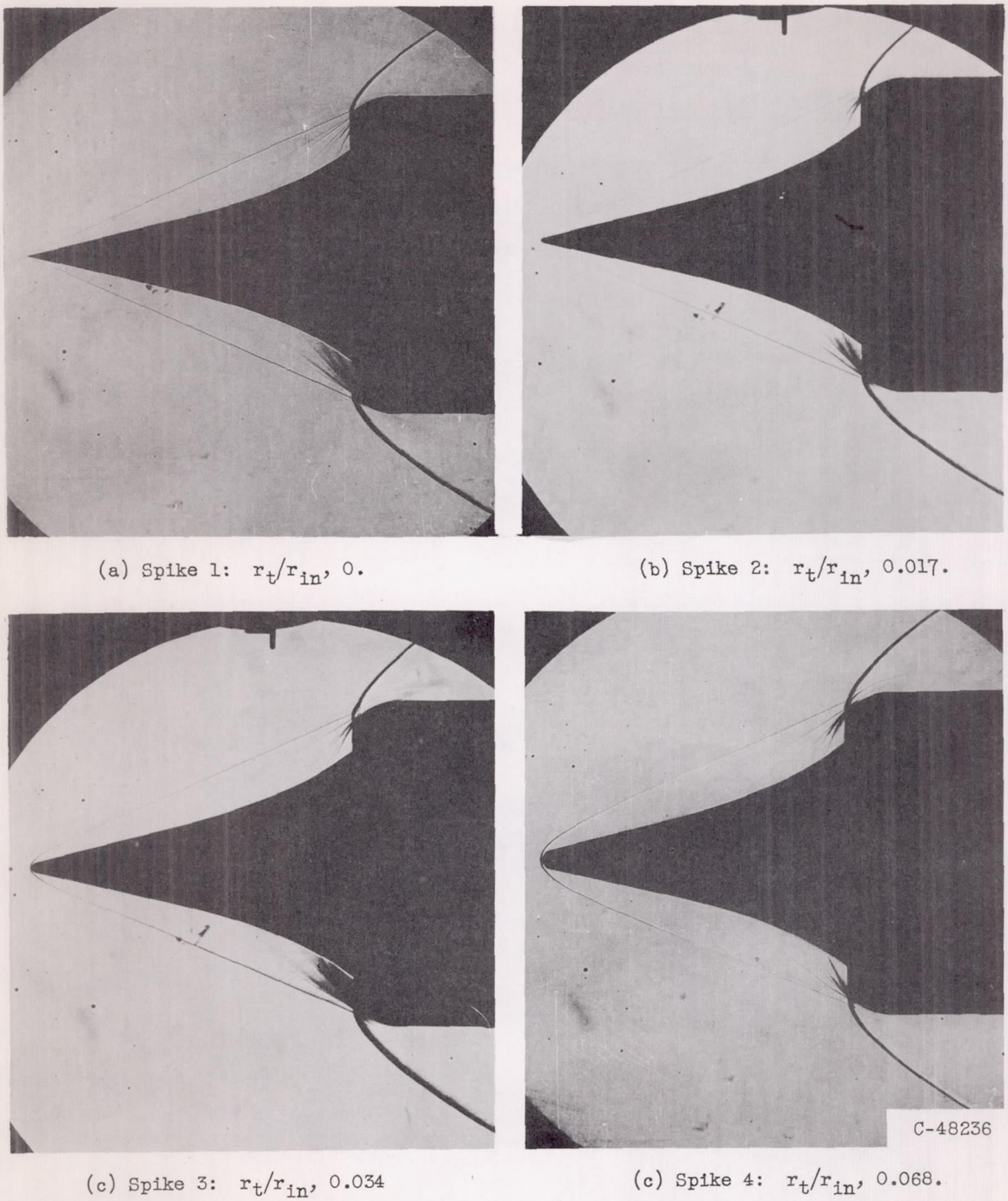


Figure 11. - Cowl static-pressure distributions.

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(a) Spike 1: r_t/r_{in}, 0.

(b) Spike 2: r_t/r_{in}, 0.017.

(c) Spike 3: r_t/r_{in}, 0.034

(c) Spike 4: r_t/r_{in}, 0.068.

Figure 12. - Schlieren photographs of supercritical inlet operation with various spike tips and sharp-lipped cowl.

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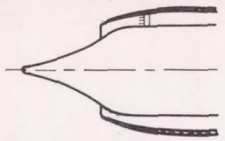
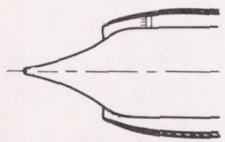
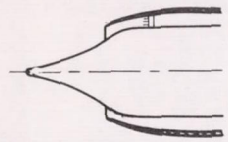
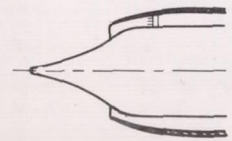
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NOTES: (1) Reynolds number is based on the diameter of a circle with the same area as that of the capture area of the inlet.

(2) The symbol * denotes the occurrence of buzz.

INLET BIBLIOGRAPHY SHEET

Report and facility	Description			Test parameters				Test data				Performance		Remarks
	Configuration	Number of oblique shocks	Type of boundary-layer control	Free-stream Mach number	Reynolds number $\times 10^{-6}$	Angle of attack, deg	Angle of yaw, deg	Drag	Inlet-flow profile	Discharge-flow profile	Flow picture	Maximum total-pressure recovery	Mass-flow ratio	
CONFID. RM E58G02a 10- by 10-foot supersonic wind tunnel		Isen-tropic	Ram scoop	3.0	2.89	0	0	√		√	√	0.81	0.77* to 0.90	Various degrees of spike-tip and cowl-lip blunting were examined for their effects on inlet performance.
CONFID. RM E58G02a 10- by 10-foot supersonic wind tunnel		Isen-tropic	Ram scoop	3.0	2.89	0	0	√		√	√	0.81	0.77* to 0.90	Various degrees of spike-tip and cowl-lip blunting were examined for their effects on inlet performance.
CONFID. RM E58G02a 10- by 10-foot supersonic wind tunnel		Isen-tropic	Ram scoop	3.0	2.89	0	0	√		√	√	0.81	0.77* to 0.90	Various degrees of spike-tip and cowl-lip blunting were examined for their effects on inlet performance.
CONFID. RM E58G02a 10- by 10-foot supersonic wind tunnel		Isen-tropic	Ram scoop	3.0	2.89	0	0	√		√	√	0.81	0.77* to 0.90	Various degrees of spike-tip and cowl-lip blunting were examined for their effects on inlet performance.

Bibliography

These strips are provided for the convenience of the reader and can be removed from this report to compile a bibliography of NACA inlet reports. This page is being added only to inlet reports and is on a trial basis.

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